eLearning based on the Semantic Web

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Abstract: eLearning is efficient, task relevant and just-in-time learning grown from the learning-requirements of the new, dynamically changing, distributed business world. The term „Semantic Web" encompasses efforts to build a new WWW architecture that enhances content with formal semantics, which enables better possibilities for navigating through the cyberspace and accessing its contents. As such, the Semantic Web represents a promising technology for realizing eLearning requirements.

This paper presents an approach for implementing the eLearning scenario using Semantic Web technologies. It is primarily based on ontology-based descriptions of content, context and structure of the learning materials and thus provides flexible and personalized access to these learning materials.

Introduction

It is clear that new styles of learning are some of the next challenges for every industry. Learning is a critical support mechanism for organizations to enhance the skills of their employees and thus the overall competitiveness in the new economy (Drucker 2000). The incredible velocity and volatility of today's markets require just-in-time methods for supporting the need-to-know of employees, partners and distribution paths. It is also clear that this new style of learning will be driven by the requirements of the new economy: efficiency, just-in-time delivery and task relevance.

Time, or the lack of it, is the reason given by most businesses for failing to invest into learning. Therefore, learning processes need to be efficient and just-in-time. Speed requires not only a suitable content of the learning material (highly specified, not too general), but also a powerful mechanism for organizing such material. Also, learning must be a customized on-line service, initiated by user profiles and business demands. In addition, it must be integrated into day-to-day work patterns and needs to represent a clear competitive edge for the business. Learning needs to be relevant to the (semantic) context of the business (Adelsberger et al. 2001).

eLearning aims at replacing old-fashioned time/place/content predetermined learning with a just-in-time/at-work-place/customized/on-demand process of learning. It builds on several pillars, viz. management, culture and IT (Maurer&Sapper 2001). eLearning needs management support in order to define a vision and plan for learning and to integrate learning into daily work. It requires changes in organizational behavior establishing a culture of "learn in the morning, do in the afternoon". Thus, an IT platform, which enables efficient implementation of such a learning infrastructure, is also needed. Our focus here lies on IT (Web) technology that enables efficient, just-in-time and relevant learning. Current Web based solutions don't meet the above mentioned requirements. Some pitfalls are e.g. information overload, lack of accurate information or content that is not machine-understandable.

The new generation of the Web, the so-called Semantic Web, appears as a promising technology for implementing eLearning. The Semantic Web constitutes an environment in which human and machine agents will communicate on a semantic basis (Berners-Lee 2000). One of its primary characteristics, viz. shared understanding, is based on ontologies as its key backbone. Ontologies enable the organization of learning materials around small pieces of semantically annotated (enriched) learning objects (Neidl 2001). Items can be easily organized into customized learning courses and delivered on demand to the user, according to her/his profile and business needs .

The paper will outline how the Semantic Web can be used as a technology for realizing sophisticated eLearning scenarios. In the following, we will first sketch requirements for eLearning. Thereafter, we analyze the representational structures that are offered by the Semantic Web (common semantics, machine-processable and -understandable data) and discuss layers of the Semantic Web architecture. In the subsequent section, the advantages of using ontologies for describing eLearning materials are presented. We continue with a description of an ontology-based approach for eLearning. After a discussion of related work, concluding remarks summarize the importance of the presented topics and outline some future work.

eLearning and eLearning requirements

"eLearning is just-in-time education integrated with high velocity value chains. It is the delivery of individualized, comprehensive, dynamic learning content in real time, aiding the development of communities of knowledge, linking learners and practitioners with experts" (Drucker 2000).

Standard or traditional learning processes can be characterised by centralised authority (content is selected by the educator), strong push delivery (instructors push knowledge to students), lack of a personalisation (content must satisfy the needs of many) and the linear/static learning process (unchanged content). A detailed view on standard learning is given in Tab.1. However, such an organisation of the learning process results in an expensive, slow and too unfocused (problem-independent) learning process. Dynamically changing business environments put completely different challenges on the learning process - it has to be efficient, just-in-time and task relevant (problem-dependent), as mentioned in first section. This can be solved with eLearning, i.e. with a distributed, student-oriented, personalised, and non-linear/dynamic learning process. Tab. 1 shows the characteristics (or pitfalls) of the standard learning scenario and the improvements achieved using the eLearning approach. These are also the most important characteristics of eLearning.

Dimensions	**Training**	**eLearning**
Delivery	Push – Instructor determines agenda	Pull – Student determines agenda
Responsiveness	Anticipatory – Assumes to know the problem	Reactionary – Responds to problem at hand
Access	Linear – Has defined progression of knowledge	Non-linear – Allows direct access to knowledge in whatever sequence makes sense to the situation at hand
Symmetry	Asymmetric – Training occurs as a separate activity	Symmetric – Learning occurs as an integrated activity
Modality	Discrete – Training takes place in dedicated chunks with defined starts and stops	Continuous – Learning runs in the parallel to business tasks and never stops
Authority	Centralized – Content is selected from a library of materials developed by the educator	Distributed – Content comes from the interaction of the participants and the educators
Personalization	Mass produced – Content must satisfy the needs of many	Personalized – Content is determined by the individual user's needs and aims to satisfy the needs of every user
Adaptivity	Static – Content and organization/taxonomy remains in their originally authored form without regard to environmental changes	Dynamic – Content changes constantly through user input, experiences, new practices, business rules and heuristics

Table 1 Differences between training and eLearning (Drucker 2000)

The principle behind eLearning is that the tools and knowledge needed to perform work are moved to the workers – wherever and whoever they are. Simply put, eLearning revolves around people. This is in stark contrast to the way learning has typically involved people flocking around the learning, i.e. a typical scholastic environment.

eLearning has its origins in computer-based training (CBT), which was an attempt to automate education, replace a paid instructor, and develop self-paced learning. But, the focus of eLearning extends and improves the CBT scenario by a learning approach that removes the barriers of time and distance, and customizes learning to the user's and business' needs (Barker 2000). Key to success is the ability to reduce the cycle time for learning and to adapt "content, size and style" of learning to the respective user and its business environment.

Semantic Web architecture - XML, RDF and Ontologies

The term „Semantic Web" encompasses efforts to build a new WWW architecture that enhances content with formal semantics. That means, content is made suitable for machine consumption, as opposed to content that is only intended for human consumption. This will enable automated agents to reason about Web content, and produce an intelligent response to unforeseen situations.

Layers of the Semantic Web

"Expressing meaning" is the main task of the Semantic Web. In order to achieve that objective several layers of representational structures are needed. They are presented in the figure 1 (Berners-Lee 2000), among which the following layers are the basic ones:

- the XML layer, which represents the structure of data;
- the RDF layer, which represents the meaning of data;
- the Ontology layer, which represents the formal common agreement about meaning of data;
- the Logic layer, which enables intelligent reasoning with meaningful data.

It is worth to note that the real power of the Semantic Web will be realized when people create many systems that collect Web content from diverse sources, process the information and exchange the results with other human or machine agents. Thereby, the effectiveness of the Semantic Web will increase drastically as more machine-readable Web content and automated services (including other agents) become available. This level of inter-agent communication will require the exchange of "proofs".

Two important technologies for developing the Semantic Web are already in place: the eXtensible Markup Language (XML) and the Resource Description Framework (RDF).

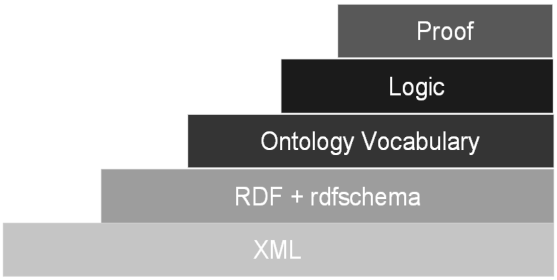

Figure 1 Layers of the Semantic Web architecture

XML (http://www.w3.org/XML/) lets everyone create its own tags that annotate Web pages or sections of text on a page. Programs can make use of these tags in sophisticated ways, but the programmer has to know what the page writer uses each tag for. In short, XML allows users to add arbitrary structure to their documents but says nothing about what the structures mean (Erdmann & Studer 2000). Meaning of XML-documents is intuitively clear, due to "semantic" mark-up and tags, which are domain-terms. However, computers do not have intuition. Tag-names per se do not provide semantics.

Data Type Definitions (DTDs) are a possibility to structure the content of the documents. However, structure and semantics are not always aligned, they can be orthogonal. Therefore, a DTD is not an appropriate formalism to describe the semantics of an XML document.. The same holds for XML-Schema (http://www.w3.org/XML/Schema) – it only defines structure, though with a richer language. In essence, XML lacks a semantic model: it has only a "surface model", a tree. So, XML is not the solution for propagating semantics through the Semantic Web. It can only play the role of a "transport mechanism", viz. as an easily machine-processable data format.

The Resource Description Framework (RDF) (http://www.xml.com/xml/pub/98/06/rdf.html) provides a means for adding semantics to a document. RDF is an infrastructure that enables encoding, exchange and reuse of structured metadata (described later). Principally, information is stored in the form of RDF statements, which are machine understandable. Search engines, intelligent agents, information broker, browsers and human users can understand and use that semantic information. RDF is implementation independent and may be serialized in XML (i.e., its syntax is defined in XML). A process in which semantic information is added to the web documents is called semantic annotation (Handschuh et al. 2001). RDF, in combination with RDFS (http://www.w3.org/TR/PR-rdf-schema/), offers modeling primitives that can be extended according to the needs at hand. Basic class hierarchies and relations between classes and objects are expressible in RDFS. In general, RDF(S) suffers from a lack of formal semantics for its modeling primitives, making interpretation of how to use them properly an error-prone process.

A solution to this problem is provided by the third basic component of the Semantic Web, viz. ontologies. In philosophy, an ontology is a theory about the nature of existence, about what types of things exist; ontology as a discipline studies such theories. Artificial Intelligence and Web researchers have co-opted the term for their own jargon, and for them an ontology describes a formal, shared conceptualization of a particular domain of interest.

Ontologies are specifications of the conceptualization and corresponding vocabulary used to describe a domain (Gruber 1993). They are well-suited for describing heterogeneous, distributed and semistructured information sources that can be found on the Web. By defining shared and common domain theories, ontologies help both people and machines to communicate concisely, supporting the exchange of semantics and not only syntax. It is therefore important that any semantic for the Web is based on an explicitly specified ontology. By this way consumer and producer agents (which are assumed for the Semantic Web) can reach a shared understanding by exchanging ontologies that provide the vocabulary needed for discussion.

Ontologies typically consist of definitions of concepts relevant for the domain, their relations, and axioms about these concepts and relationships. Several representation languages and systems are defined. A recent proposal

extending RDF and RDF Schema is OIL (Ontology Interchange Language) (Fensel et al. 2001). OIL unifies the epistemologically rich modeling primitives of frames, the formal semantics and efficient reasoning support of description logics and mapping to the standard Web metadata language proposals. The DAML+OIL language (http://www.daml.org/2001/03/reference.html) has also been developed as an extension to XML and RDF. It heavily relies on OIL and is a similar representation language for describing web resources and supporting inference over those resources.

Semantic Web & eLearning

The key property of the Semantic Web architecture i.e. (common-shared-meaning and machine-processable metadata), enabled by a set of suitable agents, establishes a powerful approach to satisfy the eLearning requirements: efficient, just-in-time and task relevant learning. Learning material is semantically annotated and for a new learning demand it may be easily combined in a new learning course. According to his/her preferences, a user can find and combine useful learning material very easily. The process is based on semantic querying and navigation through learning materials, enabled by the ontological background.

In fact, the Semantic Web can be exploited as a very suitable platform for implementing an eLearning system, because it provides all means for (eLearning): ontology development, ontology-based annotation of learning materials, their composition in learning courses and (pro)active delivery of the learning materials through eLearning portals. More details about the eLearning scenario will be given in the last section. In the following (Tab. 2) a summary view of the possibility to use the Semantic Web for realizing the eLearning requirements is presented.

Requirements	eLearning	Semantic Web
Delivery	Pull – Student determines agenda	Knowledge items (learning materials) are distributed on the web, but they are linked to commonly agreed ontologie(s). This enables construction of a user-specific course, by semantic querying for topics of interest.
Responsiveness	Reactionary – Responds to problem at hand	Software agents on the Semantic Web may use a commonly agreed service language, which enables co-ordination between agents and proactive delivery of learning materials in the context of actual problems. The vision is that each user has his own personalised agent that communicates with other agents.
Access	Non-linear – Allows direct access to knowledge in whatever sequence makes sense to the situation at hand	User can describe the situation at hand (goal of learning, previous knowledge,...) and perform semantic querying for the suitable learning material. The user profile is also accounted for. Access to knowledge can be expanded by semantically defined navigation.
Symmetry	Symmetric – Learning occurs as an integrated activity	The Semantic Web (semantic intranet) offers the potential to become an integration platform for all business processes in an organisation, including learning activities.
Modality	Continuous – Learning runs in parallel to business tasks and never stops	Active delivery of information (based on personalised agents) creates a dynamic learning environment that is integrated in the business processes.
Authority	Distributed – Content comes from the interaction of the participants and the educators	The Semantic Web will be as decentralised as possible. This enables an effective co-operative content management.
Personalization	Personalized – Content is determined by the individual user's needs and aims to satisfy the needs of every user	A user (using its personalised agent) searches for learning material customised for her/his needs. The ontology is the link between user needs and characteristics of the learning material.
Adaptivity	Dynamic – Content changes constantly through user input, experiences, new practices, business rules and heuristics	The Semantic Web enables the use of distributed knowledge provided in various forms, enabled by semantical annotation of content. Distributed nature of the Semantic Web enables continuous improvement of learning materials.

Table 2 Benefits of using Semantic Web as a technology for eLearning

Metadata & eLearning

This section gives an overview of the current metadata standards for eLearning and discusses the problems in shared-understanding, which arise when using these conventional metadata. It outlines the enhancement that is achieved by using an ontology-based solution (ontology-based metadata) applied in our e-Learning scenario (cf. the subsequent section).

Conventional Metadata for eLearning

Compared to traditional learning in which the instructor plays the intermediate role between the learner and the learning material, the learning scenario in eLearning is completely different: instructors no longer control the delivery of material and learners have a possibility to combine learning material in courses on their own. So the content of learning material must stand on its own. However, regardless of the time or expense put into creating advanced training material the content is useless, unless it can be searched and indexed easily. This is especially true as the volume and types of learning content increase.

One solution lies in using metadata. Metadata is the Internet-age term for information that librarians traditionally have used to classify books and other print documents. At its most basic level, metadata provides a common set of tags that can be applied to any resource, regardless of who created it, what tools they used, or where it's stored. Tags are, in essence, data describing data. Metadata tagging enables organizations to describe, index, and search their resources and this is essential for reusing them.

In the eLearning community three metadata standards are emerging to describe eLearning resources: IEEE LOM (http://ltsc.ieee.org/doc/wg12/LOM3.6.html), ARIADNE (http://ariadne.unil.ch/Metadata/) and IMS (http://www.imsproject.org/metadata/imsmdv1p2/imsmd_infov1p2.html). Those meta-models define how learning materials can be described in an interoperable way. All the metadata elements necessary to describe a resource can be classified into several categories, each offering a distinct view on a resource.

For example, the LOM standard contains the following metadata levels:
- general - groups all context-independent features plus the semantic descriptors for the resource;
- lifecycle - groups the features linked to the lifecycle of the resource;
- meta-metadata - groups the data elements describing the metadata that indexes the document;
- technical - groups data elements describing the technical features of the document;
- educational - groups educational and pedagogic data elements for the resource;
- rights - groups data elements pertaining to the conditions of use for the resource;
- relation - groups data elements that describe the linkage between the subject and other resources;
- annotation - groups data elements that allow comments on the educational use of the resources;
- classification - groups data elements that describe the position of the resource in an existing classification system.

Different communities have developed their own standardized metadata vocabularies to meet their specific needs. However, most of those metadata standards lack a formal semantics. Although these standards enable interoperability within domains, they introduce the problem of incompatibility between disparate and heterogeneous metadata descriptions or schemas across domains.

This lack of a shared understanding between terms in one vocabulary as well as between terms in various metadata vocabularies might be avoided by using ontologies as a conceptual backbone in an eLearning scenario.

Ontology-based metadata

The role of an ontology is to formally describe shared meaning of the used vocabulary (set of symbols). In fact, an ontology constrains the set of possible mapping between symbols and their meanings. But the shared-understanding problem in eLearning occurs on several orthogonal levels, which describe several aspects of document usage, as sketched in Fig. 2.

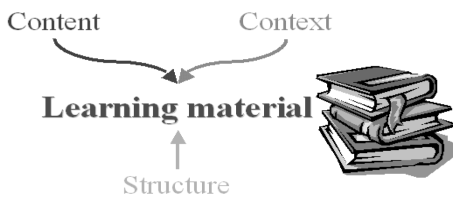

Figure 2 From the student point of view the most important criterions for searching learning materials are: what the learning material is about (content) and in which form this topic is presented (context). However, while learning material does not appear in isolation, another dimension (structure) is needed to encompass a set of learning materials in a learning course.

Metadata for describing the content of learning materials

The shared-understanding problem in eLearning occurs when one tries to define the content of a learning document in the process of providing learning materials as well as in the process of accessing to (searching for) particular learning material.

In an eLearning environment there is a high risk that two authors express the same topic in different ways. This means semantically identical concepts (i.e. topics of eLearning-content) may be expressed by different terms from the domain vocabulary. For example, one may use the following semantically equivalent terms for the concept "Agent": *agent, actor, contributor, creator, player, doer, worker, performer*. The problem can be solved by integrating a domain lexicon in the ontology and thus defining mappings from terms of the domain vocabulary to their meaning as defined by the concepts of the ontology. E.g. in our example *agent, actor, contributor, creator*,

player, doer, worker, performer are symbols used in the real world and they are all mapped to the same concept *Agent* in the domain ontology. Also, in the process of providing information, ontological axioms play an important role. For example, an axiom that states that two relations are mutually inverse relations is used for checking consistency of provided information, as described in the next section.

From the point of view of the user there is the problem of what terms or keywords to use when searching for learning materials. Simple keyword queries are valuable in situations where users have a clear idea of what they are seeking and the information is well-defined. It doesn't hold for eLearning, where the viewpoints and the knowledge levels of the author and the users of learning materials may be completely different. Therefore, some mechanism for establishing shared understanding is needed. Second, simple keyword searches cannot pick up synonyms ("*Agent*" and "*Actor*"), abbreviations ("*World Wide Web*" and "*WWW*"), different languages („*house*" (English) and „*Haus*" (German)) and often not even morphological variations ("*Point-to-Point Network*" and "*Point to Point Network*"), not to mention the context of the query. This problem can be resolved by defining corresponding relations (e.g., synonym, abbreviation) in the domain ontology. Ontological relations are also used in the process of navigating through learning materials (for example, it is reasonable to "jump" from the topic "*Network*" to the topic "*Protocol*").

Metadata for describing the context of learning materials

Learning material can be presented in various learning or presentation contexts. We may e.g. distinguish learning contexts like an *introduction*, an *analysis* of a topic, or a *discussion*. An *example* or a *figure* are some usual presentation contexts. The context description enables context-relevant searching for learning material according to the preferences of the user. For example, if the user needs a more detailed explanation of the topic, it is reasonable to find learning material which describes an example of the given topic. In order to achieve a shared-understanding about the meaning of the context vocabulary (e.g. intro or introduction) a context-ontology is used.

Metadata for describing the structure of learning materials

Because eLearning is often a self-paced environment, training needs to be broken down into small bits of information ("lego" learning) that can be tailored to meet individual skill gaps and delivered as needed. These chunks of knowledge should be connected to each other in order to be able to build up a complete course from these chunks. Learning material is usually more complex in its structure than continuous prose, so it requires greater care in its design and appearance. Much of it will not be read continuously. The structure isn't a static one, because a course structure is configured depending on the user type, the user's knowledge level, his or her preferences and the semantic dependencies that exist between different learning chunks, e.g. an example might depend on first giving the corresponding definiton. But, again shared understanding about used terms is also needed for describing the structure of a learning course.

Several kinds of structuring relations between chunks of learning material may be identified. Some of them are: *Prev*, *Next*, *IsPartOf*, *HasPart*, *References*, *IsReferencedBy*, *IsBasedOn*, *IsBasisFor*, *Requires*, *IsRequiredBy*. There exist semantic connections between some of these relations that may be defined by axioms: for example, *IsPartOf* and *HasPart* are mutually inverse relations. The corresponding axiom may be exploited when searching for information. Without the definition of the inverse relation, searching for information would depend on the way metadata were provided from the author of the learning material. If one defines that some learning material named "*X*" "*IsBasedOn*" some other learning material named "*Y*", there is no possibility (without programming or explicit specification) to find all learning materials the learning material "Y" "*IsBasisFor*".

The reader may note that these three dimensions of metadata also appear in the conventional metadata model (content = classification metadata, context = educational/pedagogical metadata, structure = relational metadata). However, our metadata are ontology-based metadata and have therefore a precisely defined semantics The semantic basis results in a better semantic description of learning materials and better searching for useful materials according to user preferences.

Semantic Web-based eLearning scenario and preliminary experiences

Based on the discussion in the previous section, this section presents an overall architecture of our ontology-based eLearning scenario. The architecture of the system is represented in Fig. 3. The knowledge warehouse acts as a metadata repository and the Ontobroker system (Decker et al. 1999) is an principal inferencing mechanism. Core modules, as depicted in Fig. 3, correspond to primary activities in an eLearning environment:

- providing information from authors
- accessing the learning materials by readers and authors by querying and by browsing.

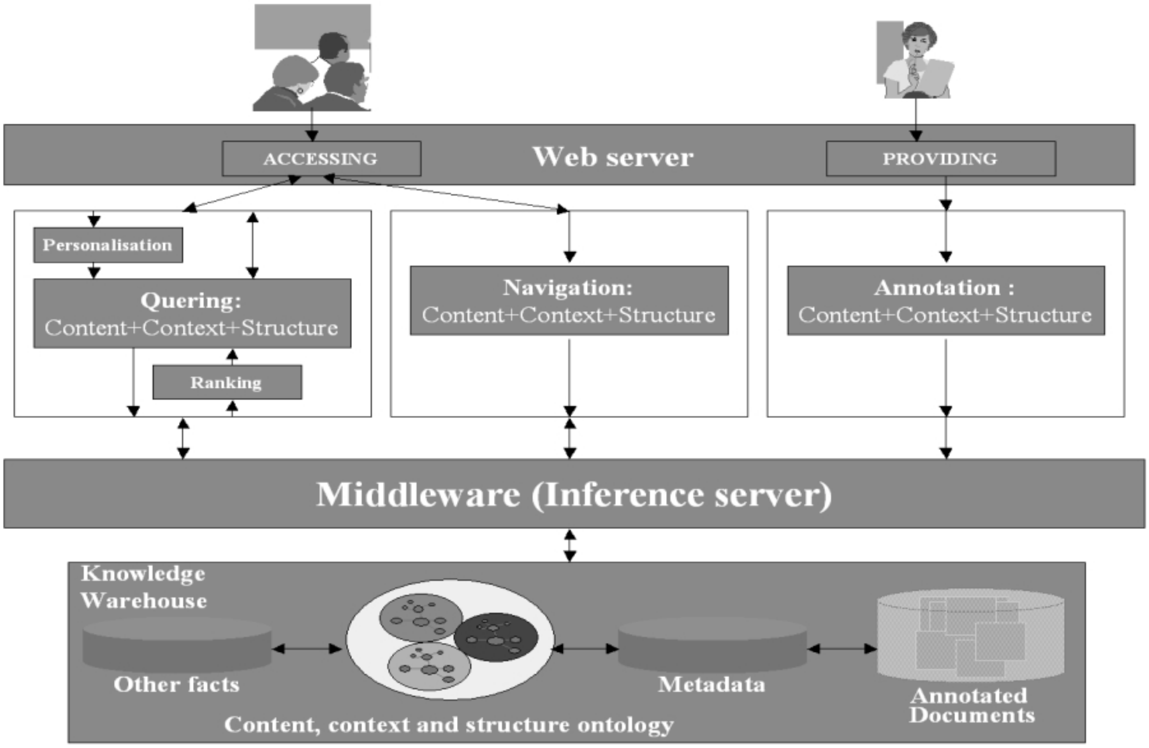

Figure 3 Architecture of an eLearning Portal

Ontology

The backbone of the system is the course ontology presented partially in the Table 3. The ontology definition contains an is-a hierarchy of relevant domain concepts, relations between these concepts, further properties of concepts (attributes with value ranges), and the derivation rules to infer new knowledge. The leftmost column shows the concepts of the domain organized in the is-a hierarchy. For example, "*PhDStudent*" is a subconcept of the concept "*Student*". Attributes and relations of concepts are inherited by subconcepts. Multiple inheritance is supported as a concept may fit into different branches of the taxonomy. Attributes and relations of the concepts appear in the middle column in the Tab. 3. Relations refer to other concepts, like "*hasAuthor*" denoting a relation between the concept "*Document*" and the concept "*Author*". The rightmost column shows some rules of the course ontology. For example, the fourth rule in Tab. 3 asserts that whenever a document D2 is known to have a child document D1 then D2 has D1 as its parent document. This kind of rules completes the knowledge and frees a knowledge provider to provide the same information at different places reducing the development as well as the maintenance efforts. The ontology representation language is F-Logic (Kifer et al. 1995). Roughly, the statements *ConceptX::ParentX* and *ConceptX[relationXY=>>ConceptY]* could be read as *ConceptX* is a subconcept of the concept *ParentX* and *ConceptX* is in the relation r*elationXY* with *ConceptY*, respectively.

The course ontology consists of content, context and structure ontology, mentioned in the previous section. The content ontology is visible in the description of domain terms like "*Protocol*", "*Service*", "*Topology*". The relation "*hasTopic*" and the first two rules are also a part of the content ontology. The first rule determines the transitive property of the "*hasTopic*" relation (Maedche et al. 2001). For example, based on the first rule and on the facts that "*eLearning hasTopic TeleTeaching*" and that "*TeleTeaching hasTopic WebBasedLearning*", the fact "*eLearning hasTopic WebBasedLearning*" is concluded (http://www.aifb.uni-karlsruhe.de/Personen/index.html). The second rule ensures that whenever a document with the content "*eLearning*" is searched for, then the documents about "*TeleTeaching*" and "*WebBasedLearning*" are also found.

The context ontology is based on the pedagogical model. Concepts like "*Introduction*", "*Explanation*", "*Example*" are used to describe several types of contexts for the learning materials.

The most important part of the structure ontology are the relations between learning materials ("*preDocument*", "*nextDocument*", "*IsBasedOn*", "*IsBasisFor*") and corresponding rules. The learning materials are organized in a tree structure. The relations "*preDocument*" and "*nextDocument*" describe a sequence of the documents at the same level in the structure tree of the learning materials. The relations "*parentDocument*" and

"*firstChildDocument*" correspond to the references between two successive structure levels. The rules in the structure ontology enable a flexible semantic navigation through the learning materials organized into a course. For example, the rule "*FORALL D1, D2 D1:Document[prevDocument->>D2] <-> D2:Document[nextDocument->>D1].*" enables to go through the learning materials in two direction (forward or backward), even though only one "path" is defined. The concepts "*Course*", "*Module*" and "*Atom*" are also part of the structure ontology. They are used to indicate the complexity of the learning materials. The simplest type of the learning materials is an "*Atom*". It is a learning material that doesn't contain any other learning material. The "*Modul*" consists of several atoms organized in a sequence and a "*Course*" is a sequence of modules or other courses. In this way a course is a tree structure of learning materials on different granularity levels. Complex structures can be derived automatically from more elementary ones by exploiting the last rule in Table 3.

Concept	Relation	Rule

Object [ ].
Document :: Object.
...
Content :: Object.
Protocol :: Content.
Service :: Content.
Topology :: Content.
Bustopology :: Topology.
Circletopology ::Topology.
...
Context::Object.
Introduction:: Context.
Explanation:: Context.
Example:: Context.
Figure::Example.
...
Structure::Object.
Course:: Structure.
Module:: Structure.
Atom:: Structure.
...
Person::Object.
Author :: Person.
Student :: Person.
PhDStudent :: Student.
...
	Document [
	name=>>String;
	title=>>String;
	path=>>String;
	hasAuthor=>>Author;
	
	content=>>Content;
	context=>> Context;
	structure=>> Structure;
	...
	prevDocument =>> Document;
	nextDocument =>> Document;
	firstchildDocument =>> Document;
	parentDocument =>> Document;
	relatedDocuments =>> Document;
	...
	IsBasedOn=>>Document;
	IsBasisFor=>>Document;
	...].
	
	Content[
	hasTopic=>>Content].
		FORALL A, B, C
		A[hasTopic->>C] <- A:Content and A[hasTopic ->>B] and B:Content and B[hasTopic ->> C] and C: Content.
		
		FORALL D, C1, C2
		D:Document[content->>C1] <- C1:Content and C2 :Content and D:Document[content->>C2] and C1[hasTopic->>C2].
		
		FORALL D1, D2
		D2:Document[prevDocument->>D1] <-
		EXISTS E1, E2, C C:Content andD2:Document[context->>E2] and E2:Example and D1[context->>E1] and E1:Explanation and D1[content->>C] and D2[content->>C].
		
		FORALL D1, D2
		D1:Document[parentDocument->>D2] <-
		D2:Document[firstchildDocument->>D1].
		
		FORALL D1, D2
		D1:Document[prevDocument->>D2] <->
		D2:Document[nextDocument->>D1].
		
		FORALL D, S
		D:Document[structure->>S:Course] <-
		Exists D1, S1 D1:Document and (S1:Course or S1:Module) and D1[structure->>S1] and D1[parentDocument->>D].
		…

Table 3 Partial ontology in the eLearning scenario

All others elements of the course ontology, represented in the Tab. 3, correspond to the common metadata. For example, the attributes "*name*", "*title*", "*path*", which describe the "*Document*" concept, are equivalent to the general metadata level in the previously mentioned LOM standard.

Providing the learning materials

The first phase is the production of learning materials that may be used or reused in the construction of training courses. In order to provide learning material, which could be suitable for metadata-searching, each learning material has to be described or "enriched" with the following metadata information:

- what is the learning material about (content annotation),
- which context has the learning material (context annotation) and
- how is it connected to other learning materials (structure annotation).

This "enriching" consists of explicitly adding to each learning material a set of metadata information referring to the course ontology. Providing information is for now constrained to manually entering metadata information (facts) or to filling in ontology-based HTML forms. The metadata may be placed within the document itself (e.g. HTML <META> tags) or in some external metadata repository (e.g. an RDF repository) (Handschuh et al. 2001). In our approach it is stored externally in the knowledge warehouse.

Accessing the learning materials

In the process of information accessing, the ontology is used for:

1) Semantic querying for learning materials: A semantic query is based on the three dimensional search space (content, context, structure) that is defined by the ontology. An easy-to-use interface based on the query capabilities of the F-logic query interface of Ontobroker (Decker et al. 1999) is offered for specifying such queries.

2) Conceptual navigation through the collection of learning materials based on ontological relations between concepts in the (a) content and (b) context ontologies and on the explicit (navigational) structure defined from the author in the structure ontology (c).

(a) postulates an assumption that the semantically relevant links for the learning material correspond to the ontological relations. Two pieces of learning material indexed with two concepts that are related in the ontology are hyperlinked to each other in the user interface. For example, in the telematics domain the learning material that describes OSI layers has hyperlinks to the corresponding protocol-, service- and interface- learning materials, because the concept "OSI layer" has relations with the concept "protocol" in the telematics ontology.

(b) Navigation is also based on the rules in the context ontology. The rules describe how to organize the learning materials about the same content in a proper structure. For example, from the pedagogical point of view the learning material that explains some content must precede the learning material that is an example of the same content. It means that each learning material with a context "*Explanation*" has (hyper)links to the learning materials about the same content that have the context "*Example*".

(c) The navigational structure consists of the ordering of learning material in the learning course (first, next, parent), but it is also created by authors who define related learning materials that do not obligatory correspond to the content ontology.

Other components

The knowledge warehouse serves as a repository for data represented in the form of RDF statements. The knowledge warehouse itself hosts the ontology, the metadata, as well as the data proper. The system uses the inference engine of the Ontobroker system (Decker et al. 1999). Particularly, the inference engine answers queries and it performs derivations of new knowledge by an intelligent combination of facts in the knowledge warehouse with the ontology. The possibility to derive additional factual knowledge that is only provided implicitly frees knowledge providers from the burden of specifying each fact explicitly. Methods for personalization and semantic ranking of the results of querying the knowledge warehouse are described in (Maedche et al. 2001).

Related work

There are only a few approaches that could be compared to our eLearning scenario. The most similar approach is the system Karina (Crampes et al. 2000), which enables dynamical building of the learning courses according to user preferences. It is based on the conceptual description of learning material using conceptual graphs and uses some (prerequisite) strategies to fulfil the users' objectives in the search/navigation process. A sibling of Karina, the Sybil system (Crampes et al. 2000) uses an ontology of pedagogy for defining the context of the learning course. However, both approaches do not describe explicit an structure of the course (structure ontology in our case). The Collaborative Courseware Generating System (Qu et al. 2001) uses modern web technologies (XML, XSLT, WebDAV) for describing course structures, but without explicit ontology support. It also does not define the context and structure of the learning materials explicitly. The Ontology-based Intelligent Authoring Tool (Chen et al. 1998) uses an intelligent training system in the eLearning scenario. It uses four ontologies (domain, teaching strategies, learner model and interfaces ontology) for the construction of the learning model and the teaching strategy model, but it fails in exploiting modern Web technologies. To summarize, none of the mentioned systems uses the advantages of the Semantic Web, which is the main point in our approach.

Conclusion

"Making content machine-understandable" is a popular paraphrase of the fundamental prerequisite for the Semantic Web. In spite of its potential philosophical ramifications this phrase must be taken very pragmatically: content (of whatever type of media) is 'machine-understandable' if it is bound (attached, pointing, etc.) to some formal description of itself. This vision requires the development of new technologies for web-friendly data description. The Resource Description Framework (RDF) metadata standard is a core technology used along with other web technologies like XML. Ontologies are (meta)data schemas providing a controlled vocabulary of concepts, where each concept comes with an explicitly defined and machine processable semantics. By defining shared and common domain theories, ontologies help both people and machines to communicate concisely, supporting the exchange of semantic content instead of syntactic structures.

In this paper we have presented an eLearning scenario that exploits ontologies in three ways: for describing the semantics (*content*) of the learning materials (this is the domain dependent ontology), for defining the learning *context* of the learning material and for *structuring* the learning materials in the learning courses. This three-dimensional, semantically structured space enables easier and more comfortable search and navigation through the learning material.

The purpose of this paper was to clarify possibilities of using the Semantic Web as a backbone for eLearning. Primarily, the objectives are to facilitate the contribution of and the efficient access to information. But, in general, a Semantic Web-based learning process could be a relevant (problem-dependent), a personalised (user-customised) and an active (context-sensitive) process. These are prerequisites for realizing efficient learning. This new view enables us to go a step further and consider or interpret the learning process as a process of managing knowledge in the right place, at the right time, in the right manner in order to satisfy business objectives.

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